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1. REPORT DATE <b>SEP 2007</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2007 to 00-00-2007</b>	
4. TITLE AND SUBTITLE <b>Characterization of the Variability of the Ocean Acoustic Environment</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>Naval Research Laboratory,Stennis Space Center,MS,39529</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>See also ADM002047. Presented at the MTS/IEEE Oceans 2007 Conference held in Vancouver, Canada on Sep 29-Oct 4, 2007.</b>					
14. ABSTRACT <b>See Report</b>					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>3</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

# Characterization of the Variability of the Ocean Acoustic Environment

J. Paquin Fabre and Steven M. Dennis  
Naval Research Laboratory  
Stennis Space Center, MS 39529, USA

**Abstract-** Great strides have been made in the ability to model and predict oceanography (temperature, salinity, currents, etc.) accurately and in a timely manner. There exists a need to characterize the variability of the ocean based on its acoustic propagation characteristics. That is, how and where does the evolution or variability of the environment significantly impact the acoustic propagation characteristics of an oceanographic waveguide? Due to the complexity of the acoustic propagation in a waveguide, variability in the oceanography is not always indicative of the variability in the acoustic propagation. For example, a significant change in temperature in an area may not significantly impact the acoustic propagation in the area. There is also a limit on the ability to sense the oceanography. Sensor availability and coverage, as well as time put constraints on efforts to measure a large ocean area. The work presented here shows that analysis of acoustic variability computed using predicted oceanography over an area provides a better insight into the oceanographic variability for the purposes of sensor placement.

Acoustic coverage integrated over many source depths is a representation of how energy travels in a waveguide and can therefore provide a good estimate of the propagation properties of the environment over a large area. A method of estimating the acoustic variability over a period of time using this integrated acoustic coverage (IAC) computation, which is derived from estimated transmission loss is presented here. Two and three dimensional oceanographic model predictions of temperature and salinity (converted to sound velocity) over a time period are used as inputs to the acoustic model. The parabolic equation Range-dependent Acoustic Model (RAM, [Collins, M. D., "Applications and time-domain solution of higher-order parabolic equations in underwater acoustics," *J. Acoust. Soc. Am.*, 86 (3), 1097-1102, 1989]) is used to compute the complex pressure and transmission loss (TL) for calculation of a range independent IAC. This quantity is computed for each time period and variability over time is computed for the ocean volume (longitude, latitude and depth). The RAM is then run for range dependent (RD) environments across user-selected, highly variable tracks for estimation of (range dependent) IAC variance. The acoustic computation is currently done over the whole area in a range independent mode to save computation time. The capability to compute along selected tracks adds a necessary RD evaluation of the areas with the most variability. Comparisons of the range independent (RI) IAC over the volume and RD over the highly variable track show that the use of the range independent IAC parameter is valid for acoustic variance estimation over an area.

This work shows that the integrated range independent acoustic variability provides a better estimate of variability than does the oceanographic variability, for the purposes of sensor placement. As work continues, more capability can be added to include functionality such as range dependence.

## I. INTRODUCTION

Acoustic propagation is typically computed along tracks from source locations to receiver locations. A challenge arises in characterizing an entire area acoustically because of the nature of this geometric problem. Typically, the area is gridded, a source is placed at each grid point and transmission loss (TL) is run in several directions to characterize the receipt of acoustic pressure from that particular source using TL or signal excess (SE), that is the amount of signal remaining once noise and other factors are estimated. Or, reciprocity can be assumed to characterize the receiver at the grid point with sources out along the bearings. This method can be problematic for several reasons, first due to the non-linear nature of the acoustic transmission problem, interpolation between points or across azimuths is not strictly valid. Second, because of the amount of information at each grid point, visualization of the results of this type of analysis is challenging. Finally, acoustic model runs can be computationally intensive so the characterization of an area can take a significant amount of run time.

This paper addresses these challenges by introducing an integrated acoustic coverage (IAC) and using it to examine the variability of an area over an ensemble of oceanographic fields.

## II. METHOD

This effort is part of ongoing work to acoustically characterize an underwater environment and its variability as it applies to acoustics over time or over ensembles of the environment (sound speed, bathymetry, sediment, wind). Because of the relationship between propagation and the sound speed profile or its gradient (which determines the propagation angle) it seems as though examining the acoustic gradient or its variability would provide a significant insight into the acoustic variability, however, due to frequency dependence and bottom interactions, this can be misleading. A more accurate acoustic metric is the acoustic coverage of the area.

For the purposes of this effort, each grid point is a receiver and that receiver's coverage is defined as the possible source locations in which the signal excess is positive, or the TL allows a source to be detected. Figure 1 shows an example of a number of radials (8) from a single receiver location with the covered ranges indicated by shading. The coverage is computed as the area of the shaded portions of the plot (Figure

1). This calculation must be done for each grid point and each acoustic frequency of interest. If single source depths are of interest, each source depth must also be computed, but for the purposes of this work, the sources are integrated over all depths.

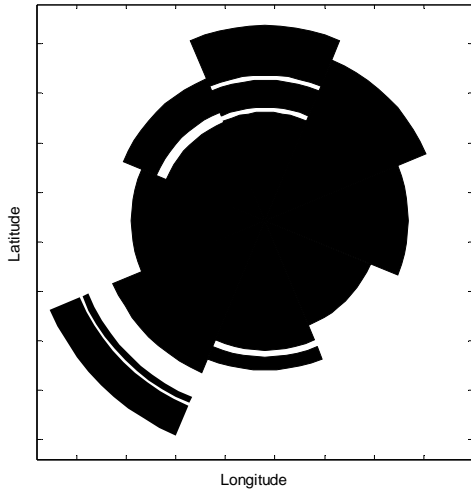


Figure 1. Coverage sector plot for a single location using eight radials. Filled sectors indicate areas where the TL is below the FOM and therefore energy from the source would arrive at the receiver.

Acoustic coverage integrated over many source depths is a representation of how energy travels in a waveguide and can therefore provide a good estimate of the propagation properties of the environment over a large area. Two and three dimensional oceanographic model predictions of temperature and salinity (converted to sound velocity) over a time period are used as inputs to the acoustic model. RAM (Collins, 89) is used to compute the TL and subsequently a range independent IAC. Due to the significant run times required to generate this RD coverage diagram for each snapshot or ensemble member, range independent IAC is computed. Another effort has addressed characterizing how range dependent or non-adiabatic the environment is (Dennis and Fabre, 2007). A figure of merit (FOM) of 83 dB is selected to compute the IAC, so any ranges along the track that have less than 83 dB loss are used in the area computation.

This IAC is computed for each grid point at each time period or ensemble and variability over time or ensemble is computed for the ocean volume (longitude, latitude and depth). Because many environments are non-adiabatic, the RAM can then be run for RD environments across user-selected tracks for estimation of RD IAC variance.

### III. RESULTS

As a typical example, the variability across a 20 member oceanographic ensemble in an area off the west coast of the US shows that the variability in the integrated sound speed gradient (Figure 2) is most significant in the western portion of the area, whereas the RI-IAC for 100Hz (Figure 3) and 500 Hz (Figure 4) are most variable in the southeast section of the area with a significant amount of variability at 100Hz in the western area. If there are multiple frequencies of interest, the coverage variances can also be integrated over frequency to provide a summary-type plot (Figure 5) that can be useful for

selecting RD tracks to run. In order to determine the range dependent variability across those areas, RD tracks were run across each area. Results from two of the tracks, marked as A, in the western part of the area, and B in the southeastern part of the area; and shown as dotted lines in Figure 2, are shown here.

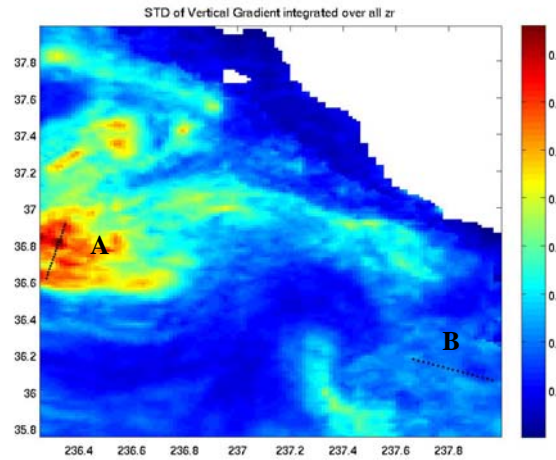


Figure 2. Variability (standard deviation) of vertical sound speed gradient (color) versus longitude and latitude integrated over 10 receiver depths.

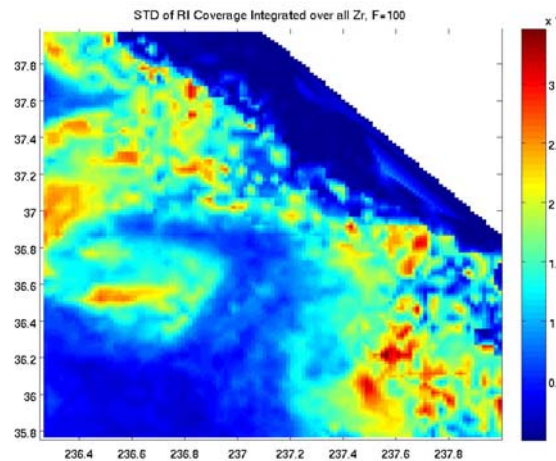


Figure 3. Variability (standard deviation) of range independent acoustic coverage (units of  $\text{km}^2$ ) (color) versus longitude and latitude integrated over all receiver depths for 100Hz.

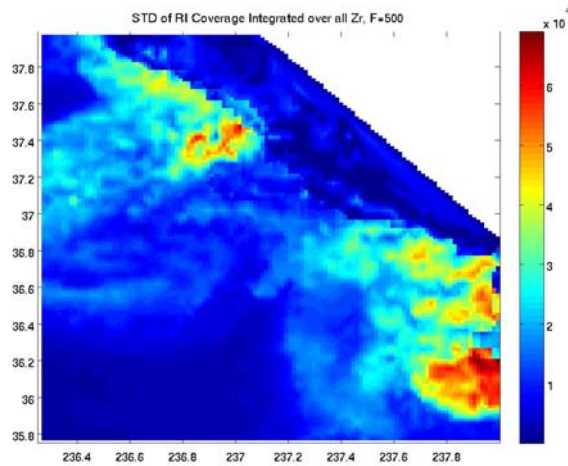


Figure 4. Variability (standard deviation) of range independent acoustic coverage (units of  $\text{km}^2$ ) (color) versus longitude and latitude integrated over all receiver depths for 500Hz.

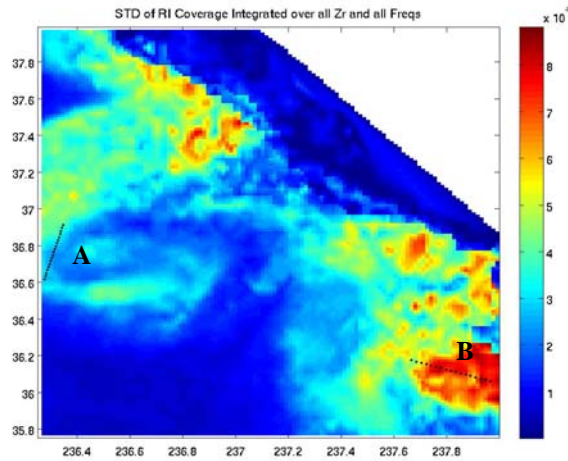


Figure 5. Variance (standard deviation) of RI IAC (units of  $\text{km}^2$ ) (color) versus longitude and latitude integrated over receiver depth and two frequencies.

The RD IAC was computed for each of these tracks as if that were the only bearing at the grid point. The standard deviations of those coverages over the ensemble are summarized in Table 1. If the variability of the TL with range is examined, it doesn't necessarily indicate the variance of the coverages. For example, coverages can vary significantly depending on where the TL curves cross a FOM line. Additionally, due to its logarithmic nature, many TL curves vary significantly over time or ensemble at high losses, whereas losses greater than the FOM will never be considered in the coverage computation.

Table 1 summarizes the RD IAC ( $\text{km}^2$ ) results for track A and track B for each receiver and frequency. Table 1 shows that track B, in the southeast section of the area, where the RI IAC was highest, gives a better estimate of the variability of the RD IAC than does the variability of the sound speed gradient, track A.

These results are typical approximately 75-80 % of the time. With more frequencies and receiver depths, the method would likely be more robust, at the cost of the run time. Because the RI IAC does not consider cross range

propagation, this method can break down in highly range dependent areas. The results are also dependent upon the FOM, therefore the user must have some familiarity with the propagation compared to the parameters that go into the FOM. While not a perfect system, it provides a good, systematic tool for characterized the environmental acoustic variability.

Table 1. Summary of STD of RD track coverages (units  $\text{km}^2$ ) for two areas. Receiver depth, frequency and standard deviation over the ensemble for the two tracks shown in Figure 2 using an 83 dB FOM.

Zr	Frequency	Track A	Track B
50	100	18.05	82.77
100	100	0.00	148.26
150	100	0.00	143.67
200	100	18.26	173.54
250	100	18.26	96.01
300	100	30.43	113.97
500	100	19.63	160.57
750	100	36.02	167.45
1000	100	56.94	137.02
50	500	5.38	319.92
100	500	243.47	323.33
150	500	59.80	167.23
200	500	26.57	168.66
250	500	22.06	206.74
300	500	24.68	164.84
500	500	34.01	109.77
750	500	50.88	111.01
1000	500	66.86	90.01
	Mean	40.63	160.27
	Sum	731.29	2884.78

#### IV. CONCLUSIONS

This work shows that the integrated range independent acoustic coverage variability provides a better estimate of acoustic performance variability than does the oceanographic variability. This IAC variability can be used for several applications, such as sensor placement, for example, sensors can be placed where the variability over an ensemble is high. It can be used to determine the variability over time for fixed sensor analysis. And it can also be used for understanding the acoustic variability of an area for the purposes planning acoustic exercises.

While work remains to be done and other acoustic metrics are being explored, the use of the RI-IAC provides a good estimate of the acoustics over an area for the purposes of characterizing the variability of the environment.

#### ACKNOWLEDGMENTS

The authors would like to thank Dr. Stanley Chin-Bing and Dr. David King for helpful discussions on this topic. The authors appreciate and acknowledge the funding support from the Naval Research Laboratory Base Program.

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